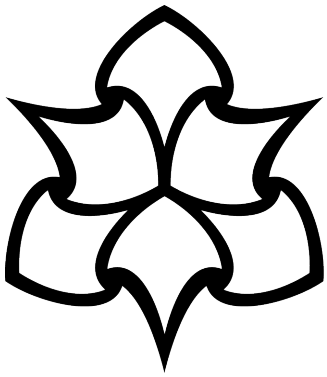

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EARLY YEARS LEARNING AT THE SCIENCE MUSEUM
Rapid Evidence Assessment

Prepared for Science Museum Group and
The Helen Hamlyn Trust

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EXECUTIVE SUMMARY

The Early Years Learning at the Science Museum project involves a collaboration between the Science Museum Group (SMG) and the Helen Hamlyn Centre for Pedagogy (0-11 years) (HHCP) at the UCL Institute for Education. The proposal for a Rapid Evidence Assessment (REA) was made by the HHCP as part of the collaborative work on a proposal to the Helen Hamlyn Trust. Once the project grant was confirmed, the HHCP was commissioned by SMG to undertake this REA to advance understanding of 0-8 year-old children's engagement with objects in science museums. The review focuses on peer-reviewed reports of research published from 2000 to 2019 and was funded by The Helen Hamlyn Trust as part of a collaborative research project lead by the SMG.

This report is based on a review of 43 peer-reviewed publications, which present the findings of qualitative and quantitative studies conducted in science museums, science centres, natural history museums, art galleries/museums, and children's and national museums that house STEM-related collections and exhibits.

The review addresses the following Research Questions:

1. How do young children aged 0-8 years engage with museum objects related to Science, Technology, Engineering and Maths (STEM)?
2. What innovative ways can be found to enhance young children's curiosity and engagement with museum objects related to STEM?

KEY FINDINGS

Our review of literature has found that most young children perceive museums as places where they see 'special things'. They enjoy exploring museum exhibits on their own and having the freedom and choice where to focus their attention. There are multiple factors that contribute to children's engagement with specific objects in science museums, and to their enjoyment of museum visits with their families, friends and in nursery or school groups. These include how children relate to the objects they see, how objects are displayed, their visibility at different child heights, how gallery spaces are designed and how children are encouraged to explore museum exhibits through their interactions with others and through diverse experiences that support their learning in science museums.

RQ1: How do young children aged 0-8 engage with museum objects related to STEM?

Research evidence suggests that:

1.1 There is wide variation in individual children's interest in different museum objects. However, research suggests the following object characteristics tend to spark most children's curiosity and recall:
- large objects;
- small object collections;
- authentic objects;
- familiar objects;
- unfamiliar objects or familiar objects presented in unusual contexts;
- humorous objects

1.2 Research evidence implies that children are particularly motivated to want to find out about objects when:
- the objects relate to their knowledge, experience and interests;
- the object display is conducive to social interaction;
- children can touch and manipulate the objects;
- children are able to exercise choice and control over where to focus their attention, but this agency is balanced by a degree of structured support or activity.

1.3 Research findings imply that children engage more deeply with objects when there is social interaction around the objects between adults and children, and between children. Dialogue, exploratory talk, and collaborative inquiry between children and adults and between peers are most effective to deepen children's engagement and enhance their understanding in museum environments.

1.4 Children engage deeply with museum objects when they are able to experience exhibits kinaesthetically and through multiple senses, and when there is scope for them to engage creatively in activities related to the object.

1.5 Children tend to be motivated to learn when museum experiences are relevant to their everyday life and when they can make connections between the museum world and their own world, for example, when object displays invite children to explore and discuss the differences and similarities between familiar and unfamiliar objects in familiar and unfamiliar contexts. Family members have uniquely rich knowledge of their children's interests and experiences, and can optimise children's engagement and understanding of museum objects by making connections between exhibits and children's everyday life.

1.6 Museum experiences that support young children's learning tend to be: familiar; contextualised; storified (learning through stories and dramatization); play-based; kinaesthetic (involving children's action); multi-sensory; and promote children's freedom to choose what they engage in.

1.7 The most effective museum spaces for young children's learning are inviting, rich in interesting exhibits, and fun. Children's learning is enhanced when strong learning support systems are built into the room arrangement and display design.

1.8 Children's learning is further enhanced when responsive staff set a welcoming atmosphere and guide children's learning through their interactions, including dialogue that seeks children's perspectives and builds on their prior knowledge and skills ('funds of knowledge' – see Glossary).

RQ2. What innovative ways can be found to enhance young children's curiosity and engagement with museum objects related to STEM?

2.1 Pre-visit activities in class or at home, using digital and non-digital resources, can help to familiarise children with objects, and enhance their engagement with objects during their museum visits.

2.2 On gallery, digital technologies offer new ways to prompt children's enquiry and enthusiasm about objects, such as exploring objects with microscopes attached to digital projections, remote-control devices, light boxes and digital cameras. Digital simulator games offer potential for children to explore the purposes of real objects in virtual environments. Interactive Mobile and Sensory Guide Systems (MGS) are highly effective in engaging children during museum visits, particularly (but not exclusively) for young children with sensory and mobility impairment. The World-

Wide Web offers further opportunities for pre- and post-visit activities related to specific museum objects.

2.3 Research has identified potential barriers to young children's engagement with museum objects, including:
- objects being displayed without meaningful context;
- when children feel their behaviour is being closely surveilled and restricted, and their freedom to roam and find their own pathways through museum galleries is constrained;
- when there is no structure or support to prompt children's deep engagement
- when accompanying adults are unsure how to foster children's engagement with objects;
- when there is little or no scope or prompts for social interaction around objects;
- when museum object displays are difficult to access or in remote spaces in a gallery;
- when museum displays are potentially emotionally distressing (such as animal skeletons) – this may be overcome by adding humour to displays.

2.4 Research suggests that optimal conditions for young children's learning in museums involves some adult-child, peer-peer and child-object interactions, and points to the needs for innovation on-gallery about how to design for interaction. Examples from research include, for example:
- providing accompanying adults (parents, extended family and teachers) with prompts and ideas about how to engage and extend children's attention, both in the form of printed or digital gallery guides, with information about objects and object labels that are written in the voice of the child, to be read aloud;
- creating interactive object displays that children can see, touch, feel, smell, make things happen, and experience with their bodies as well as their minds and imagination;
- planning a suite of experiences that build threads of meaning for children to understand key concepts, the purpose of objects, their uses and their stories. These experiences might take place both within and outside the immediate museum environment, and involve object-focussed activities in which children can participate.

2.5 Research highlights the multiple roles that museum educators and accompanying adults play when interacting with children, including when they:
- scaffold learning (see Glossary);
- engage children in dialogue (see Glossary);
- guide children's participation (see Glossary);
- act as co-enquirer/ co-learner/ co-player;
- explain things to children;

2.6 This review found no high quality research reporting on how children's own individual collections might influence their interest in and understanding of museum objects. However, one study reports that when young children are encouraged to create their own small-scale museums (e.g. in a classroom) by collecting and curating objects that matter to them, they may develop greater understanding of the curatorial process and the role of museums as guardians of significant objects.

GLOSSARY OF KEY TERMS

Dialogic learning

Teaching and learning based on the exchange of views between two or more people on equal terms. Dialogue is an essential feature of the communicational dynamics that lie at the heart of learning. Scaffolding, guided participation and dialogue all involve contingent responses to the moves made by the learner, and are rooted in sociocultural theory (Vygotsky 1978). An important difference is that guided participation and dialogic teaching do not require the withdrawal of support (see Scaffolding).

Funds of Knowledge

This concept refers to the knowledge base generated by families, based on their everyday experiences, including family members' work experiences, social practices and social histories (Moll et al. 1992). Families, including children, are experts in their own knowledge base, and the role of educators is to learn from children and families about their unique funds of knowledge, and to plan learning that connects with and extends this knowledge base.

Guided Participation

Refers to how children learn in particular social and cultural contexts, and clarifies how adults help children to understand how to act in new situations (Rogoff 1990). For example, by providing emotional cues, non-verbal models of how to behave, verbal and non-verbal interpretations of behaviour and events, and verbal labels to classify objects and events. These adult activities are coupled with young children's efforts (intentional or not) to pick up information about social situations, social practices, people and artefacts in their environment. Guided participation can offer a more inclusive framework than scaffolding, which is strongly oriented towards talk and is imbued with cultural assumptions about communication, teaching and learning.

Objects

Three-dimensional items that are cared for, studied and displayed by museums on behalf of the nation. In Science Museums, the focus is on objects that relate to science, technology, engineering, mathematics, medicine or media, including artwork, digital and non-digital objects.

Scaffolding

Support provided by a 'more knowledgeable other' (MKO) (Vygotsky, 1978) (adult or peer) that enables children to build their skills and complete tasks that they are unable to complete unaided. Scaffolding involves responding contingently to each child's 'level'. The MKO controls elements of a task that are initially beyond the learner's capacity, so the child can gradually extend what they can manage on their own, and the MKO then withdraws support. Wood, Bruner and Ross (1976: 96) describe scaffolding as 'luring the child into actions that produce recognizable-for-him solutions'. Scaffolding theory has been critiqued for placing too much emphasis on the adult role, and for paying insufficient attention to the child's responses to different learning situations.

1. INTRODUCTION

The Early Years Learning at the Science Museum project involves a collaboration between the Science Museum Group (SMG) and the Helen Hamlyn Centre for Pedagogy (0-11 years) (HHCP) at the UCL Institute for Education. The proposal for a Rapid Evidence Assessment (REA) was made by the HHCP as part of the collaborative work on a proposal to the Helen Hamlyn Trust. Once the project grant was confirmed, the HHCP was commissioned by SMG to undertake this REA to advance understanding of 0-8 year-old children's engagement with objects in science museums.

The review focuses on peer-reviewed reports of research published from 2000 to 2019 and was funded by The Helen Hamlyn Trust as part of a collaborative research project lead by the SMG. The review aims to offer a firm foundation grounded in research evidence for the Science Museum to develop an innovative programme that will inspire young children's curiosity in object-rich galleries, and help them to understand the relevance of science in their own lives.

For the purpose of the REA, we define museums as informal, public learning environments that house specialist object collections and exhibits. Although the focus is young children's learning with objects in science museums, we include various types of museum in our review, namely: science museums, science centres, children's museums and national museums that house STEM-related collections and exhibits, as well as lessons learnt from young children's engagement with objects in natural history museums and art galleries/museums. This wider perspective reflects a) the relative paucity of research on young children's engagement with object collections in science museums, and b) the diversity of objects that make up science museum collections (See Appendix 1).

With such rich collections of cultural heritage entrusted to them, museum professionals are increasingly interested in how to provoke young children's curiosity in STEM-related objects by designing spaces, and by planning encounters and activities that will spark children's interest and imagination. Equally, museum professionals need to know how best to support young children's learning through their interactions with children and accompanying adults, including teachers, parents, carers and extended family.

The review addresses the following Research Questions:

1. How do young children aged 0-8 years engage with museum objects related to STEM?

   Aims:

   - To determine the characteristics of objects that children find interesting.
   - To determine what children want to find out about the objects.
   - To determine what motivates children to want to find out about the objects.
   - To determine how important the environment around the objects is for children's engagement.

2. What innovative ways can be found to enhance young children's curiosity and engagement with museum objects related to STEM?

   Aims:

   - To determine what the best facilitation methods are for accompanying adults and museum staff to enhance young children's curiosity and engagement.
   - To determine, if any at all, the ways in which children's own collections support their understanding of museum objects.
   - To determine key challenges that impede children's curiosity and engagement.

2. RECOMMENDATIONS

The following recommendations are based on the REA findings, and are presented with a view to informing Phase 2 of the 'Early Learning in the Science Museum' project. Phase 2 aims to pilot innovation in the ways that the Science Museum encourages young children's engagement with STEM-related objects.

HOW DO YOUNG CHILDREN AGED 0-8 YEARS ENGAGE WITH MUSEUM OBJECTS RELATED TO STEM?

2.1 Investigate what types of objects children find interesting in SMG museums

2.1.1 Focus on a variety of objects and features that research suggests appeal to young children (e.g. large, small and precious, authentic, familiar, unfamiliar in a familiar context, humorous, a combination), and conduct child audience research to find out what other objects visitors to the Science Museum are interested in. Participatory research with young child and adult visitors could lend unique insights.

2.1.2 For objects that may not be familiar to children, find a balance between creating a context for the objects with which children can identify, and allowing children to use their own imaginations about objects.

2.1.3 Consider the potential of stories and performance about objects to create contexts in which children can deepen their understanding of objects.

2.2 Find out what questions young children ask about the objects in SMG museums. Is there a pattern in what they want to know?

2.2.1 Plan a series of encounters for children with and about objects and their relevance to life in the past, present and/or future, so children can engage deeply with the objects and their significance. Note the questions they ask and comments they make, and then plan object displays and activities around these aspects of children's curiosity.

2.2.2 Conduct wider research into this topic through short questionnaires for accompanying adults about the kinds of questions children ask prior to, during and after museum visits.

2.3 Develop a range of approaches designed to motivate children to want to find out about the objects, and to deepen their learning.

2.3.1 Make museum experiences relevant to children's knowledge, interests and everyday lives, by finding out from children what interests them. We recommend participatory research with young children, parents and educators to inform this aspect of Phase 2 of the study.

2.3.2 Display some objects in surprising/ quirky ways to see if this makes them more appealing to children.

2.3.3 Use stories and performance to create meaningful context for objects.

2.3.4 Ensure that museum educators model effective communication strategies that prompt children's visual thinking skills and talk through dialogue and open-ended

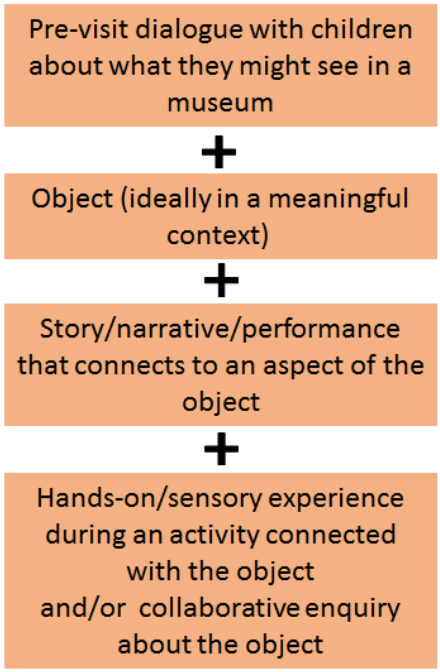
questions, and offer tips for accompanying adults on how to support children's learning through dialogue.

2.3.5 Add elements of playfulness and interactivity to support children's agency when engaging with objects. These elements can range from open-ended to more structured engagement.

2.3.6 Consider the balance between educator-led and free choice activities for children during each museum visit.

2.3.7 Experiences should address the multiple levels of children's needs to connect with objects (see example diagram).

Example of a multi-level Visitor Experience



2.4 Design museum object collection environments to spark children's curiosity and engagement.

2.4.1 Reflect on how exhibit spaces and activities can be designed in ways that prompt free choice and dialogic interactions to maximize children's roles in their own learning. Consider how activities can be designed (e.g. treasure trails, conversation spaces) to optimise dialogue.

2.4.2 Allow children freedom to play and to explore on their own, and encourage this by planning physical trails on gallery where children can make choices about which pathways to follow.

2.4.3 Provide a variety of kinaesthetic experiences for children to interact with STEM-related objects and in STEM-related museum environments.

2.4.4 Create on-gallery opportunities for children to use their bodies and all their senses, to enable embodied cognition.

2.5 What innovative ways can be found to enhance young children's curiosity and engagement with museum objects related to STEM?

2.5.1 Consider diverse ways for accompanying adults and museum staff in SMG museums to enhance young children's curiosity and engagement.

2.5.2 Museum visits should include activities founded on scaffolding, guided participation + limited choice + encouraging parent–child collaborative action and conversations (to externalise children's meaning making). This varied approach is most supportive of children's learning as it offers multiple opportunities for children to pursue their natural curiosity and individual interests.

2.5.3 Plan activities to accommodate young children's diverse communication strategies, for example, through their actions as well as through talk.

2.5.4 Create opportunities for triadic (Object + Child + Interaction) play partnerships, supported by museum staff- or sign-mediated activities.

2.5.5 Consider how digital technology can be used to guide visits (e.g. sensory guides, humorous museum mascot guides etc)

2.5.6 Consider how digital technologies can be used by children, both independently and with adult assistance and positive reinforcement, to engage children's deep interest and wonder in STEM.

2.5.7 Explore what lessons can be learnt from the children's digital software design industry, including, for example, using digital narratives to facilitate children's meaning-making around objects, or using mobile phones that allow children to make pre-visit plans, track their pathways through the museum space via GPS, and use this information to create personalised suggestions for future visits.

2.5.8 Reflect on how the Science Museum might prompt children to develop Visual Thinking Strategies (VTS) to promote the development of critical-thinking skills and language of thinking and creating. By concentrating on conversational interactions between a museum educator/accompanying adult and children (child–adults/peers interactivity), VTS starts with questions as prompts for children, encouraging them to provide evidence for their ideas.

2.5.9 Work with nursery and school groups to plan visits that reflect children's interests, to enable them to connect their life experiences and funds of knowledge with museum objects. These plans might then be used to inform the design of future experiences based on children's interests.

2.5.10 Consider how dialogues that start in museum spaces can be drawn on and extended out into children's wider lives, following their visits to museums.

2.6 Recognise and address key challenges that may impede children's curiosity and engagement in SMG museums.

2.6.1 TYPE OF OBJECT: Through audience research, conduct an audit of diverse museum objects that attract children's curiosity, and where children tend to linger and focus their attention. Conduct a similar audit of objects that do not hold children's attention, and where children do not linger. Observe and note any patterns in social interaction around particular objects.

2.6.2 CHILDREN'S INTERACTION WITH OBJECTS: Explore critically reflective questions with diverse members of museum staff, such as: Do some objects tend to prompt talk between children, and between adults and children? Under what circumstances does interaction break down?

2.6.3 OBJECT DISPLAY: Conduct a similar audit of the different ways that objects are displayed – where does sustained attention and/or interaction occur and when does it break down? What changes can be made to engage children of different ages?

2.6.4 GALLERY DESIGN: Observe how children explore objects in different galleries. Are there features in each gallery's environment that are conducive to prompting children's curiosity?

3. FINDINGS

OVERVIEW

Our literature review has shown that there is limited high quality academic and practitioner research on young children's engagement with objects in *science* museums. However, there is sufficient evidence across museum types (listed in Table 2, Section 4) to inform the development of innovative ways to engage young children with STEM museum objects.

There is strong research evidence suggesting that young children need to connect with objects on multiple levels - emotionally, physically and cognitively - through diverse experiences. Many factors influence their engagement with objects. These include:

- how museum objects relate to children's pre-existing knowledge and life experiences
- how objects are displayed in museums
- how the child's natural curiosity is supported by adults and museum spaces in ways that promote deeper learning
- how activities are planned to deepen children's engagement with objects and their significance in the past, present and future
- the individual child's motivation, enthusiasm and freedom to explore and choose where to focus their attention when visiting object-rich galleries

Most young children perceive museums as places where they can see 'special things' that they do not normally encounter in everyday life (Piscitelli 2001: 278), rather than spaces that display everyday life objects.

Young children most frequently engage with museum objects and spaces solitarily, often walking or running around museums in a seemingly random order, stopping for a while at an exhibit, and then moving on (Watson et al. 2002). They use their imagination to make sense of objects (Kelly et al. 2006), and their learning with and about objects is enhanced through collaborative engagement with adults or peers (Crowley et al. 2001).

There are particular characteristics of objects that seem to interest most young children, as detailed below.

3.1 WHAT TYPES OF OBJECTS ARE CHILDREN MOST ATTRACTED TO?

There is wide variation in individual children's interest in museum objects. However, research evidence across all museum types suggests that particular object characteristics tend to spark most children's curiosity and recall, namely objects that are:

- Large
- Small, and in object collections
- Authentic
- Familiar
- Unfamiliar or familiar objects presented in unusual contexts
- Humorous

Combinations of these characteristics (e.g. large and familiar; small and authentic) are likely to be most effective in prompting children's interest and engagement, particularly if children explore objects through the kinds of experiences described in Section 3.4 below.

LARGE OBJECTS

There is robust evidence suggesting that many young children are attracted to and tend to remember large museum objects. Examples of large objects found to spark children's curiosity include: life-sized whales, dinosaurs and giant cockroaches in natural and social history museums; a giant magnet wall and multi-media interactive huge electric iron in an art and social history museum; large-scale interactive objects in a science centre (e.g. loading balls via pulleys to activate the launch of a giant 'rocket') (Anderson et al. 2002).

Although young children name a wide range of objects as their 'favourite object', large items are the most frequently mentioned (Dockett, Main, and Kelly 2011; Munley 2012), and most frequently remembered (Piscitelli and Anderson 2001).

Children particularly remember large objects when their encounters with them are kinaesthetic or tactile (Anderson et al. 2002).

EXAMPLE: Queensland Museum, Australia (Piscitelli & Anderson 2001)

Boy (5 years old):	These are the whales hanging from the museum ceiling. They are very big. There is the daddy whale [pointing to the largest whale on her drawing] and that the mummy and baby whale.
Interviewer:	Why is that one the daddy whale? [points to large whale in drawing]
Boy:	Because he's the biggest!

SMALL OBJECT COLLECTIONS

Collections of small objects, such as fossils, gemstones, and human bones attract the attention of many children and their parents. Research shows that small objects encourage children to:

- engage in talk that helps them to understand what objects are for, what they do and why they are important
- ask for specific information about the objects
- construct narratives involving imagination and pretence

(Callanen et al. 2017; Kelly et al. 2006).

EXAMPLE: Australian Natural History, Sydney, Australia (Kelly et al. 2006)

Eva, aged under 5 years, chose to photograph a gemstone during her museum visit, and explained why she was interested in this object:

Interviewer: What is good here? … What do you like about it?
Eva: The little fairies, fairies live in there. They could even go inside the tiny holes.

AUTHENTIC OBJECTS

Young children are attracted to authentic artefacts (Dockett, Main, and Kelly 2011) and appreciate seeing the "real thing" (Munley 2012) rather than replicas (Bunce 2016b). As one young child commented: "I like this one because it is in the woods and it looks real" (Lifschitz-Grant 2018: 10).

EXAMPLE: Māori exhibition Kahu Ora, New Zealand (Clarkin-Phillips et al. 2014)

3-4 year-old children articulated their understanding of Maori culture and symbolism by talking with real Maori weavers engaged in real weaving at an exhibition of indigenous (Māori) woven cloaks (kākahu or korowai):

Child: These are the people that are still around (pointing to an opposite wall) and these are the people that have passed away. They are the weavers and all have their own korowai, see! You come over and say a karakia (incantation or blessing) to let them know you are thinking of them … Some people take a seat and talk.

Authentic objects have been found to promote rich meaning-making talk between children and parents, partly because they spark parents' genuine interest in the objects (Callanan et al. 2017). For example, Bunce (2016) found that children who perceived objects as authentic

were more likely to ask explanatory "Wh" questions (where, what, why questions), than objects they did not think were authentic.

However, young children may struggle to distinguish between objects that are real, fabricated, stuffed, alive or formerly alive (Anderson, Piscitelli and Everett 2008). For example, children struggled to identify that a taxidermied rabbit was a real rabbit, because it was not alive. However, when the taxidermied rabbit was displayed next to a toy rabbit, young children were more able to recognise that the taxidermied rabbit was real (Bunce 2016a). Placing objects within authentic and meaningful contexts, such as dioramas, can help children to recognise their authenticity, as can explicitly juxtaposing real objects with those that are evidently not real.

FAMILIAR OBJECTS

Research has found that young children show particular interest in objects that connect with their existing knowledge, experience and interests. These objects might be familiar to them through toys, picture books, and popular media, such as animals, vehicles, dinosaurs (Anderson et al. 2002), or the objects may relate to their personal interests, such as volcanoes or robots (Anderson, Piscitelli and Everett 2008; Carter 2018).

EXAMPLE: Queensland Art Gallery, Brisbane
(Anderson, Piscitelli and Everett 2008)

In the art gallery, 5-year-old Ben was drawn to a painting depicting volcanoes, noting how they relate to his personal interests and dreams: "I like volcanoes . . . and when I grow up, I am going to be a vulcanologist."

Children frequently recall familiar objects after they have visited a museum, such as rainbows and robots (Carter 2018) particularly if the objects are displayed in a meaningful context (Munley 2012).

Familiar objects can also help young children to grasp unfamiliar concepts. For example, Bunce (2016a) found that children's learning about the concept of taxidermy was facilitated by displaying a taxidermied rabbit, rather than a less well-known species.

UNFAMILIAR OBJECTS OR FAMILIAR OBJECTS PRESENTED IN UNUSUAL CONTEXTS

Young children understand that museums are places where they can find unusual and unfamiliar objects that they do not normally encounter in everyday life. Research shows that mystery objects (fossilized human or animal bones), unusual, surprising displays (a skeleton of a giraffe), and imaginative, quirky exhibits (human skeleton in a rocking chair) spark children's interest and curiosity (Callanan et al. 2017; Dockett, Main, and Kelly 2011; Kelly et al. 2006).

The contrast between the known and the unknown proves stimulating for learners (Kimble 2014). Children tend to ask more questions and engage more actively in discussions and critical thinking around unfamiliar objects and unusual displays, especially in the presence of interested adults (Callanan et al. 2017).

EXAMPLE: Redesigning a children's space at the Australian Museum (Dockett, Main, and Kelly 2011)

In one display, a crocodile had been taken out of its natural habitat, which prompted 3-year-old Jacob to reflect more deeply on the exhibit and to speculate about its natural habitat: "The crocodile—but he is supposed to be in the water."

HUMOROUS OBJECTS

Young children are often attracted to humorous objects. Evidence suggests that children notice and appreciate objects and displays that they find funny, such as a skeleton rocking in a chair or riding a bicycle, a skeleton of a bird in a cage, a dinosaur wearing a pearl necklace around its neck (Kelly et al 2006, Anderson et al. 2002).

Humorous objects are also frequently remembered by young children (Munley 2012).

EXAMPLE: Australian Natural History, Sydney, Australia (Kelly et al. 2006)

In this example, a child comments on the display of a human skeleton in a cage:

Interviewer:	What is good here? … What do you like about it?
William:	Um, it's sitting on the lounge and the skeleton is in the cage (*laughs*)

OBJECTS THAT EVOKE EMOTIONS

Objects that evoke emotional responses other than amusement can also prompt children's curiosity and engagement with objects. For example, Dockett, Main, and Kelly (2011: 23) describe how a skeleton of a giraffe with no skin was unsettling but at the same time engaging for young museum visitors. The children asked many questions about the exhibit and made suggestions to museum staff about how the exhibit might be made less scary:

> "I like giraffes but this one was scary . . . maybe you could have some pictures of ones with skin so I can see what it looked like before it died. I don't like bones!"

Research points to the importance of ensuring that museum exhibits are emotionally engaging but not intimidating for young visitors.

3.2 WHAT MOTIVATES CHILDREN TO WANT TO FIND OUT ABOUT OBJECTS, AND WHAT DO CHILDREN WANT TO FIND OUT THEM?

What children want to find out about objects is highly dependent on the nature of the object, and the significance of the object to the child's life experiences and 'funds of knowledge' (Moll et al 1992). Research suggests the following conditions tend to motivate children to want to find out about museum objects.

WHEN OBJECTS RELATE TO CHILDREN'S KNOWLEDGE AND INTERESTS

Children are particularly motivated to find out about objects that relate to their existing knowledge, experiences, and interests (Faria et al. 2015; Anderson, Piscitelli and Everett 2008). Children often revisit the same objects multiple times during each visit, and revisit objects that have aroused their interest each time they return to a museum (Hackett, Procter, and Kummerfeld 2018).

Pre-visit activities can be an effective way to provide children with beneficial background knowledge about the objects (Jant et al. 2014). Pre-exhibit activities, such as manipulating and exploring objects and object replicas, often prompt a chain of talk and actions that may be critical for children's learning in the museum: "having already explored the objects during the pre-exhibit activity, these children were now better prepared to discuss them with their parent" (p.2040).

EXAMPLE: Field Museum, Chicago, USA (Jant et al. 2014)

A pre-exhibition activity was designed to introduce children and parents to particular objects prior to their visit. Parent-child dyads received:

- exhibition objects
- conversation cards with the objects pictured on them and questions relating to the objects

Researchers concluded that manipulating and exploring the objects prior to visiting the museum can be instrumental in facilitating children's learning, transfer of knowledge, and memory.

WHEN CHILDREN CAN TOUCH AND MANIPULATE OBJECTS

Children's motivation to find out about objects is enhanced when they can touch, manipulate or make objects do things when they have moving parts and mechanisms. Children's engagement increases when they can observe the connection between cause and effect (Piscitelli and Penfold 2015), for example by manipulating a sound-producing zoetrope (Crowley et al. 2001).

Research literature contains numerous examples of the ways in which museums can enhance children's engagement with exhibits, such as exploring and making in a historic

house (Rönkkö, Aerila, and Grönman 2016), using mobile guide systems with inquiry-based, guided-learning activities and collaborative problem-solving (Andre, Durksen, and Volman 2017), pursuing treasure trails, where the exhibition becomes an adventurous space (Larsen and Svabo 2014).

WHEN THE OBJECT DISPLAY IS CONDUCIVE TO SOCIAL INTERACTION

Displays that invite interaction between adults and children or between peers (siblings, classmates) can prompt object-centred dialogue. For example, Povis and Crowley (2015) describe how families were given flashlights in a darkened gallery, and this, along with signage prompts, helped parents and children to jointly focus their attention on the same objects. This, in turn, resulted in their increased engagement in learning talk about that object.

Young children enjoy learning about objects with their peers and with adults (parents, teachers, museum staff), and this sense-making talk deepens their engagement (Munley 2012; Watson et al. 2002). As one eight-year-old commented when recalling a museum trip:

> "Learning through field trips and with people that know more and that help us, is easier. And then having to do the diary, and the various tasks of the activity, makes the learning of science more fun." (Faria et al. 2015: 990)

WHEN THERE IS A BALANCE BETWEEN STRUCTURE AND AGENCY

Children take a deeper interest in objects, when they have freedom to choose which objects to seek out and engage with, and when their choice and control (agency) is balanced with an element of structure. Research indicates that agency contributes to children's engagement and learning in museums (Hope 2018; Griffin 2004; Piscitelli and Anderson 2001), but structured activities and closed tasks may be more beneficial for achieving particular learning goals (Andre, Durksen, and Volman 2017).

Research evidence suggests that creating enjoyable and beneficial museum experiences for young children requires a fine balance between structure and agency (Munley 2012; Griffin 2004). One way to achieve this balance is to allow children to explore the museum space and engage with the objects freely on their own terms, whilst providing facilitated pre- and post-activity sessions designed to introduce children to the exhibits and help them consolidate their learning (Piscitelli and Penfold 2015).

EXAMPLE: Mirakulosum Exhibit, ZOOM Children's Museum, Vienna (Wohrer and Harrasser 2011)

This exhibit (described in 3.4 below) was designed to offer children a blend of structure and freedom. Children's visits were a fixed length (90 minutes), and included an educator-led introduction to the space, followed by freedom for children play their own way through the exhibition. Children's actions were not directed, although museum educators were always present to attend to children's emerging questions and respond to their requests for guidance.

3.3 HOW CAN MUSEUMS ENCOURAGE CHILDREN TO ENGAGE MORE DEEPLY WITH OBJECTS?

Across multiple studies in this review, research evidence suggests that multiple factors influence young children's curiosity and engagement with museum objects, including:

- **Interactivity**, which can be introduced by digital and non-digital technologies
- **Opportunities for social interaction** with both peers and adults that enhance young visitors' meaning making and learning, such as dialogue, exploratory talk, and collaborative inquiry.
- **A suite of carefully planned experiences**, both within and outside the immediate museum environment, that involve object-focussed activities in which children can actively participate.

OBJECT ENGAGEMENT AND NON-DIGITAL TECHNOLOGY

Evidence suggests that certain types of non-digital technology tend to be beneficial in deepening children's engagement with objects, such as:

- **Open-ended resources** (e.g. paper, fabric, paints, 'dress-up' clothes, construction blocks mirrors, flashlights, disco balls, and glittering lengths of fabric) that offer children opportunities to create, represent, and re-contextualise objects on their own terms, drawing on their creativity and imagination (Clarkin-Phillips et al. 2018; Piscitelli and Penfold 2015).
- **'Explorer packs'** (e.g. magnifying glasses) that bridge the gap between touch and sight (Hackett, Procter, and Kummerfeld 2018; Andre, Durksen, and Volman 2017).
- **Experiences that promote joint attention**, such as flashlights/torches used in darkened display areas that help adults and children to attend jointly to the same object. Joint attention is known to be a crucial factor in promoting learning, including around museum objects (Povis and Crowley 2015).

OBJECT ENGAGEMENT AND DIGITAL TECHNOLOGY

Research has found that a range of digital technologies can enhance children's engagement with objects, particularly when they are used to create connections between children and the object. Some effective examples include:

- Exploring objects with microscopes, remote controlled cameras (Dockett, Main, and Kelly 2011), and digital cameras (Larsen and Svabo 2014).
- Using light boxes, webcams, and projectors to prompt children's enquiry about objects (Piscitelli and Penfold 2015).
- Using computers to provide narratives to facilitate children's meaning making around objects, for example, when children press 'virtual touch machine' to hear stories (Andre, Durksen, and Volman 2017).
- Using mobile phones that allow children to make pre-visit plans, track their pathways through the museum space, create personalised suggestions for future visits, and engage in follow-up activities on the internet (Andre, Durksen, and Volman 2017).
- Using Interactive Mobile Guide Systems (MGS) to prompt inquiry-based activities, such as problem-solving quests for peer groups (Andre, Durksen, and Volman 2017).

3.4 WHAT KINDS OF EXPERIENCES IN THE MUSEUM ENVIRONMENT OPTIMISE CHILDREN'S LEARNING?

The most effective museum spaces for young children's learning have lots of well-designed displays and strong learning support systems built into the room arrangement and furniture design, as well as flexible, responsive staff who set the atmosphere and guide learning through their tours, demonstrations and informal interactions (Piscitelli and Penfold 2015).

Children tend to engage deeply in learning when museums value children's curiosity, active learning, creativity and imagination as core to their museum experience. This can be achieved by designing museum displays in ways that entice their engagement. For example, the very design of the Mirakulosum Exhibit in Vienna Children's Museum invited young visitors to climb into it and explore the science-related objects and activities inside it. Children's natural curiosity was enticed and their interest deepened by a series of scientific experiments where for they could manipulate objects and experience them through action, sight, touch and smell (Wohrer and Harrasser 2011).

Figure 1 Views of the exterior and interior of the Mirakulosum Exhibit in ZOOM Children's Museum, Vienna (Wohrer and Harrasser 2011)

FAMILIAR EXPERIENCES

Research shows that children engage deeply in learning when museum experiences are relevant to their everyday life (Faria et al. 2015) and when they can make connections between the museum world and their own world (Della Croce, Puddu, and Smorti 2019). As Hope (2018) suggests 'museum context needs to relate to other contexts in children's lives so that exploration of its 'things' becomes a natural response' (p.36).

Children's learning in museums can be optimised when family members draw children's attention to connections between exhibits and children's everyday life (Dockett, Main, and Kelly 2011). Children's learning is also enhanced when object displays invite them to explore and discuss the differences and similarities between familiar and unfamiliar objects in familiar and unfamiliar contexts (Carr et al. 2012).

EXAMPLE: Science Talk in the Children's Discovery Museum, San Jose, USA (Callanan et al. 2017: 1498)

In this study, Callanan and colleagues investigated science-relevant conversations in 82 families with children aged between 3 and 11 years during their visit to an exhibition of mammoth bones. They found that children's engagement was enhanced when their families made connections between the displays and the children's families, for example:

'This is what Uncle Ted does.'; 'They found this near where Daddy works.'

Family members also made connections between the exhibits and the child's own body, for example:

'Its [mammoth] leg bone is twice as big as your bone leg'

Family members also made links with previous visits the family had made to the same exhibition:

'This is like the tooth we saw before'.

CONTEXTUALISED EXPERIENCES

Young children are particularly interested in learning about museum objects when the objects are displayed in contexts that children recognise from customs, beliefs, and values in their own lives (Anderson et al. 2002). Such connections help to bridge the gap between new and existing knowledge (Della Croce, & Smorti 2019; Dockett, Main & Kelly 2011).

Research shows that children's learning about objects is enhanced when objects are presented in ways that enable them to see the larger narratives around the objects (Carr et al. 2018; Piscitelli and Anderson 2001). For example, research has found that children are interested in all sorts of information about objects - where the objects were originally used, what they were used for, who used them, and who created them (Prosser and Eddisford 2004). Seeing contextual details such as these as part of object display can help children to make sense of museum objects.

STORIFIED EXPERIENCES

Evidence indicates that storytelling can be a powerful tool for enhancing the engagement, learning, and recall of young museum visitors (Hope 2018; Anderson et al. 2002). Stories are a familiar and enjoyable part of children's everyday culture and have the potential to bring objects to life in visitors' minds (Andre, Durksen, and Volman 2017).

For stories to have a positive impact on children's engagement and learning in museums, they must appeal to children's imagination, engage them emotionally, and ideally also physically, and make connections to children's existing knowledge and interests (Munley 2012). Stories told by professional or gifted storytellers are highly memorable for children, who readily recall and describe live, theatre-based learning experiences, especially when the story topic is interesting and unusual (Anderson et al. 2002).

EXAMPLE: 'Unexpected Science' show at the Science Center, Queensland Museums Collaborative, Australia (Anderson et al. 2002)

Children aged 4-6 years experienced the power of story and the unusual during the Unexpected Science Show in the Queensland Science Centre, where they were enthralled by, and remembered , counter-intuitive and humorous science demonstrations.

Jack: We learned about Aboriginals …about how they write on bark.
Ingrid: Oh … yeah … This is what the sword [woomera] was like…They needed a big sword and they used to swing it over their back.
Interviewer: Who told you that?... What else did we learn, Adam?
Adam: We learned about Aboriginal paintings. We learned . . .
Jack: We were learning about Aboriginal people in the paintings. You could tell by the curvy kind of shapes that they were the people in the paintings sitting down singing.

Stories facilitate children's meaning making in museums and help them to make sense of objects that are new to them. Children seem to know this instinctively, and often make up their own stories about objects (Anderson et al. 2002; Dockett, Main, and Kelly 2011; Lifschitz-Grant 2018). The potential of stories to bridge the fervid imagination of young children and the tangible yet often unfamiliar heritage surrounding them makes storytelling a highly effective tool for museums (Hope 2018).

PLAY-BASED EXPERIENCES

Play promotes deep concentration, involvement and pleasure, and is crucial for young children's learning in museums (Hope 2018). A significant body of evidence indicates that play *is* learning. In our review of museum research, we found many examples of children engaging deeply with museum objects as they played with and around them. For example, when playing and creating sounds with a zoetrope (Crowley et al. 2001), exploring and playing in a historic house (Rönkkö, Aerila, and Grönman 2016), playing with art objects (Lifschitz-Grant 2018) and with mirrors, dress-up clothing, flashlights, disco balls, CDs and glittering lengths of fabric (Piscitelli and Penfold 2015), playing with mobile guide systems (Andre, Durksen, and Volman 2017), and engaging in adventurous treasure trails (Larsen and Svabo 2014).

Several factors need to be taken into account when planning for young children's play in museums. Firstly, this may entail fundamental re-thinking of how museum visitors are enabled to behave by the physicality of the museum spaces and design, and how visitors are permitted to behave by social and cultural norms and expectations. It is important to consider cultural nuances surrounding play and learning in young children's lives (Munley 2012) as well as individual differences. Some children prefer to investigate 'like the bigger kids' and explore the 'real' as well as play aspects of museums (Kelly et al. 2006), while some parents may be hesitant to play in public (Andre, Durksen, and Volman 2017). It is also important to understand play as a process that is experimental and social, rather than viewing play as an outcomes-driven pursuit (Piscitelli and Penfold 2015). As Hope (2018) concludes in a study of young children's meaning making around museum objects:

> If we want young children to experience effective learning in museums then we need them to feel confident to play with and explore objects there, rather than feel like they 'can't touch' the artefacts, resulting in a narrow understanding of their purpose.
>
> (Hope 2018: 39)

EXPERIENCES THAT PROMOTE CHILDREN'S AGENCY

Agency relates to the extent to which children can exercise choice and control. Research shows that agency is beneficial for children's enjoyment and learning in museums. Young museum visitors are more engaged and excited when they have opportunities to participate actively and make their own choices in museum spaces (Lifschitz-Grant 2018), and this in turn helps children to acquire and consolidate knowledge (Faria et al. 2015).

Evidence points to diverse ways that have been successful in promoting children's agency when visiting museum exhibits. These include: creating opportunities for active participation through dialogue, enquiry, hands-on activities and experiences of museum guiding (Della Croce, Puddu, and Smorti 2019; Andre, Durksen, and Volman 2017); engaging children in actual museum-making and museum curatorship (Hope 2018); and providing children with resources and uninterrupted time to engage in projects outside the museum context that are informed by their museum experiences, e.g. creating their own museum at home or in the classroom (Clarkin-Phillips et al. 2018; Eckhoff 2008).

KINAESTHETIC AND MULTISENSORY EXPERIENCES

Opportunities to handle objects through kinaesthetic and multisensory experiences play a key role in children's learning in museums and have strong educational impact (Anderson et al. 2002; Hope 2018; Kelly et al. 2006; Munley 2012; Rönkkö, Aerila and Grönman 2016). Hands-on, multi-sensorial stimulation facilitates children's meaning-making, conceptual learning, and recall by fostering tangible relationships (Hope 2018; Kelly et al. 2006), promoting deep engagement (Della Croce, Puddu, and Smorti 2019), and personal, emotional, and physical involvement and actions with objects (Wohrer and Harrasser 2011).

Research also highlights the importance of compensating for the 'separation of senses' (Larsen and Svabo 2014) that often occurs in museums, where looking but not touching is the historical norm. Offering children opportunities to experience museum spaces and objects through multiple senses - by touching, hearing, seeing, smelling, and tasting - are highly effective ways to achieve multi-sensory stimulation (Hope 2018), as are multi-sensory family treasure trails (Larsen and Svabo 2014) and storytelling (Lifschitz-Grant 2018).

Museums can also develop strategies to capture the haptic imagination, where the eye 'feels' without actual physical touch, such as when a young child placed their hands against a glass case containing a porcupine and commented "touched it, that's a spiky one" (Hackett, Procter, and Kummerfled 2018: 497). As Hope (2018) argues:

> 'If we want young children to experience effective learning in museums then we need them to feel confident to play with and explore objects there, rather than feel like they 'can't touch' the artefacts, resulting in a narrow understanding of their purpose' (p39).

3.5 WHAT KEY CHALLENGES IMPEDE CHILDREN'S CURIOSITY AND ENGAGEMENT?

The following aspects are identified in the literature as creating potential barriers to young children's engagement with museum objects, along with the absence of object engagement characteristics identified throughout this report.

DECONTEXTUALISED OBJECTS

Lack of context around the objects. Displaying objects in the absence of a meaningful context can prevent young children from making meaning of their museum experiences, particularly if the objects are unfamiliar to children and are likely to be outside their individual 'funds of knowledge' (see Glossary) (Moll et al 1992).

CLOSELY SURVEILLED AND RESTRICTED BEHAVIOUR

Restrictions put on children's behaviour by accompanying adults are known to impede children's engagement with objects in museums. Similarly, many parents feel uncomfortable about being playful with their children in museums, leading them to watch their children instead of interacting with them while they play (Andre, Durksen, and Volman 2017). Anderson, Piscitelli, and Everett's (2008) study into the clashes between children's and parents' museum visit agendas highlights how important it is for the accompanying adults to

allow children to take the lead at some points during the visit to pursue their own interests and engage with museum spaces and objects on their own terms. Similarly, Piscitelli and Penfold (2015) underscore the importance of ensuring that parents and teachers support rather than direct children's learning in museums and allow them the freedom to explore.

CONSTRAINTS ON FREEDOM TO ROAM

Young children need to have time and opportunity to make independent choices about where to focus their attention and to pursue their natural curiosity when visiting museum spaces.

Close observation of child activity in museums, which at first sight may seem random and unfocused, has shown that children's path-making gives them a sense of ownership of the space and enables them to connect with exhibits on a very personal level. Children often develop walking patterns when they revisit museums, which evolve over multiple laps through the same exhibition shapes, and these pathways become an important product and resource for their learning (Kelton et al. 2018).

For example, after repeat visits to the same museum, one child explained to her mother, "Mom, we have laps that we do" (Kelton et al. 2018: 548). Tracing the same pathways over and again builds connection with museum exhibits and spaces. Children establish meaningful ownership over exhibits through place- and meaning-making developed over multiple passes of a thickening spatial routine.

NO STRUCTURE TO MUSEUM VISITS

Although child agency and freedom to roam around museums in a solitary manner are crucial, it is beneficial to complement children's free play with some elements of guidance and structure. Furthermore, some free-choice activities (pressing buttons, operating objects) can result in insufficient understanding and frustration.

Wilde and Urhahne (2008 cited in Andre, Durksen, and Volman 2017: 61) found that open-ended tasks were less successful than closed tasks in contributing to slightly older (5th Grade) children's learning and motivation: "the children showed more interest/enjoyment with closed tasks and greater short-term and long-term retention of knowledge (after four weeks) through closed and mixed tasks".

INAPPROPRIATE OR INSUFFICIENT INTERACTION AROUND AND WITH MUSEUM OBJECTS

There is widespread evidence across quantitative and qualitative studies included in this review that a lack of contingent support to promote and deepen children's interest in objects and their significance equates with missed opportunities for learning. Adult support for learning must be contingent on individual children's funds of knowledge and responses and employ a range of pedagogic strategies, such as scaffolding, guided participation, dialogic learning, co-enquiry etc. Overly didactic explanations are counter-productive and tend to lead to children's lack of engagement.

INACCESSIBLE MUSEUM DISPLAYS AND SPACES

Museum spaces that are hard for young children to access or navigate impede their learning and engagement. In a study assessing the design of a new play and learning space for young children aged 0–5 years at the Australian Museum, children indicated that the museum layout and physical space prevented their engagement with artefacts, and they suggested multiple ways that the museum displays could be made more meaningful to them. For example, they wanted to ride a bike, as a skeleton was shown riding a bike, but they were unable to do so (Dockett, Main, and Kelly 2011).

EMOTIONALLY DISTRESSING DISPLAYS

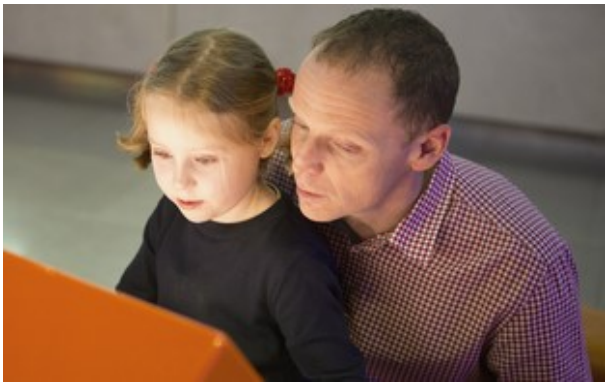
Some children may be emotionally challenged and discomforted if museum artefacts or the lifestyles depicted by the museum are different to their own experience or are intimidating (Dunn and Wyver 2019). Whilst evidence suggests that young children may be enthralled and excited by a degree of fear, this will vary widely from one child to another. It is therefore important to design potentially intimidating exhibits in ways that young children can understand and relate to within the realm of their own life experiences.

3.6 WHAT ADULT FACILITATION METHODS ARE EFFECTIVE IN ENHANCING YOUNG CHILDREN'S CURIOSITY AND ENGAGEMENT WITH MUSEUM OBJECTS?

Museum educators and adults who accompany young children during museum visits play multiple roles when interacting with children. These roles include:

1. Scaffolding learning (see Glossary)
2. Engaging children in dialogue (see Glossary)
3. Guiding children's participation (see Glossary)
4. Being a co-enquirer/ co-learner/ co-player
5. Explaining things to children
6. Facilitating learning

In addition to actively supporting children's learning, adults also have an important role to play in observing children's solitary play and engagement in museums, so they can learn about children's personal interests and choices, and a regulatory role in supervising their behaviours. Optimal conditions for young children's learning in museums involve adult-child, peer-peer and child-object interactions (Andre, Durksen and Volman 2017).



SCAFFOLDING CHILDREN'S LEARNING

Adults can promote young children's natural curiosity about objects into more substantive learning by 'scaffolding' their learning (see Glossary). That is, by offering support that is contingent on individual children's capacities and interests, and that enables them to build their knowledge and skills. Scaffolding might involve, for example:

- directing children's attention to specific aspects of an object
- asking open-ended questions
- recalling facts or experiences to encourage associations
- initiating a line of thinking that children can follow
- hypothesising, imagining or wondering (out loud) to spark children's own curiosity
- prompting with cues to support children's thinking
- posing problems
- limiting children's choices from time to time (Andre, Durksen and Volman 2017)

Scaffolding strategies are particularly effective when: the adult is genuinely interested in an exhibit, when it is clear to adults how they can support children's learning about particular objects, and when children are interested in an exhibit but struggle to find answers or solutions on their own (Puchner, Rapoport, and Gaskins 2001). Digital and virtual learning resources can also be designed to scaffold children's conceptual understanding of objects that they see in real life (Prosser and Eddisford 2004).

Through scaffolding, museum educators not only prompt young visitors to build their knowledge and follow their own interests (Della 2019) but also model for caregivers ways to optimise children's learning (Dooley and Welch 2014).

ENGAGING CHILDREN IN DIALOGUE

Dialogue is the most enabling type of talk for children's learning (Callanan et al. 2017) as it enables children to talk about their own 'funds of knowledge' (Moll et al 1992) (see Glossary). Children most frequently recall dialogic experiences in museums when they include open-ended discussion (Munley 2012). Skilful dialogue involves:

- adults directing children's attention to particular features of exhibits, making connections with child's prior knowledge and experience, extending familiar threads of engagement and affect, asking for child's opinion and giving children time to respond and contribute their own ideas (Carr 2018)
- reciprocity, where children are valued as experts in their own knowledge and interests (Clarkin-Phillips et al. 2018)

Engaging in dialogic talk between adults and children helps to create a culture of reciprocity in the teaching and learning process and provides children with the capacity to be teachers (Clarkin-Phillips et al. 2018). For example, dialogue between museum facilitators and children at the beginning of a visit or between a classroom teacher and children at school prior to a visit can help to bring together the competing agendas between children and educators, and ensure that children's interests are central to museum visits (Anderson, Piscitelli, and Everett 2008). Dialogue during collaborative activity has a positive impact on how children evaluate and explain evidence (Crowley 2001).

GUIDING CHILDREN'S LEARNING

Research suggests it is important for children to have agency during museum visits, but children's freedom to explore should be balanced with active adult guidance to optimise learning. This implies a shift in focus from child-centred to family-centred experiences in museum learning (Andre, Durksen and Volman 2017). Exhibit designers can plan triadic engagement (adults/peers, children, and objects/environment) with staff-mediated or sign-mediated activities, such as creating exhibits and activities based on co-enquiry (see next section) that interest both adults and children on multiple levels, prompting them to act as collaborative play partners (Braswell 2017).

Sensory gallery guides offer sensory structure to visits and can be particularly effective to engage young learners with sensory processing challenges (Fletcher, Blake, and Shelffo 2018). Similarly, museum visits led by museum mascot guides, in the 'flesh' or in pamphlets, offer playful routes that help children to make connections between objects, and suggest questions/prompts that parents might ask (Fletcher, Blake, and Shelffo 2018). Paper-based or digital 'Treasure Trails' designed to guide teamwork can enable children to make choices and liberate parents and teachers from feeling obliged to interpret exhibits (Larsen and Svabo 2014).

Labels can foster young children's engagement by inviting, personalizing, focusing attention, describing action, narrating, anticipating children's questions, explaining certain aspects and encouraging conversation. Labels are most effective when they are written to be read aloud, in a voice that talks to the children through the parents (Munley 2012).

CO-ENQUIRING, CO-LEARNING AND CO-PLAYING

Collaborative, enquiry-based learning is known to spark children's curiosity and foster their engagement in learning and to be rich in dialogue. Open-ended 'wh' questions (e.g. What? Why? Where?) prompt child–adult and child-child interaction, and ideally reflect and change children's understanding by focusing their attention on what is available to learn, helping them to overcome obstacles and to develop problem-solving strategies. Coupled with hands-on activities and playfulness, collaborative enquiry that is founded on triadic interaction (child–object/environment–adults/peers) results in young children being able to remember and report on what they have learnt immediately after museum visits and weeks later (Andre, Durksen and Volman 2017).

Co-enquiry activities have great potential to realise SMG's See, Think, Wonder strategy when children encounter a new object. During co-enquiry, children can be encouraged to use visual cues in museum collections to reason and to make thoughtful inference and deduction. Co-learning and co-enquiry not only deepen children's understanding but also expose them to the language of thinking through guided participation (see Glossary), conversations and questions that are posed by museum educators, accompanying adults *and* by children (Andre, Durksen and Volman 2017).

Child + Object + Adult/Peers + Environment = Optimal Learning

EXPLAINING TO CHILDREN

Explaining causation and why objects are important can deepen children's understanding, but science-related explanatory talk occurs more frequently and is more effective in hands-on exhibits than with displayed objects (Callanan et al. 2017).

Research has found that children tend to disengage if explanations are overly didactic, and that adult explanations must be contingent on child knowledge (Callanan et al. 2017). This suggests that while asking questions and wondering out loud may encourage children's engagement, providing too many explanations risks reducing children's engaged talk. Elaborative talk (including open-ended questions that encourage critical thinking and associations to prior knowledge) has been shown to prompt children's engagement in exhibits, and their recall of museum objects. It is therefore advisable to move away from overly didactic explanations and towards more responsive adult–child engagement, where the focus is on collaborative sense-making (Callanan et al. 2017)

For example, in the *Light Play* exhibition in Ipswich Art Gallery in Queensland, Australia, museum educators gauged children's prior knowledge of, and theories about, light. Key concepts, such as translucency, opacity, shadow, reflectivity, and colour-mixing, were introduced and explained through demonstrations, giving children insight into how they could play in the activity spaces, and helping to reinforce key ideas through their own exploratory play (Piscitelli and Penfold 2015).

FACILITATING LEARNING

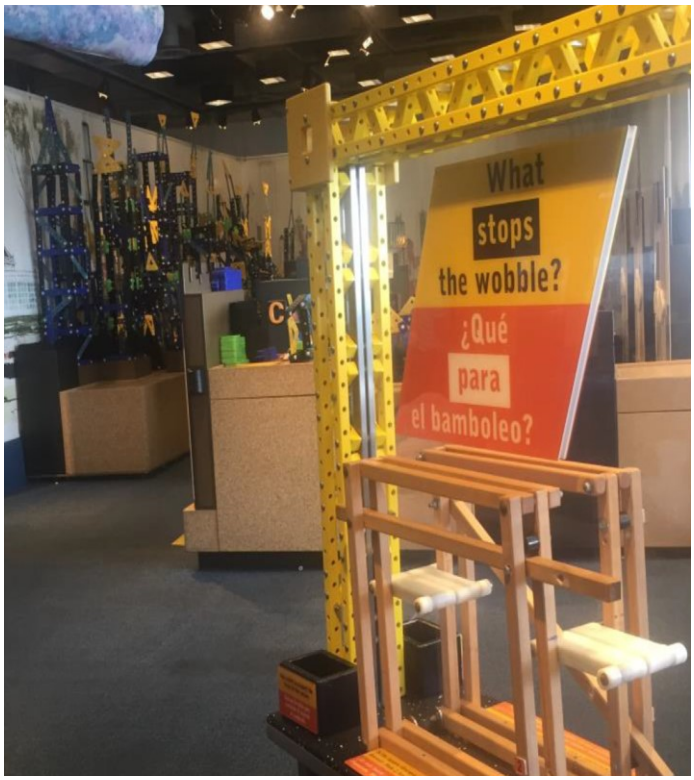
Facilitation takes many different forms and refers to the process of making learning easier. In this report, we refer to facilitation more specifically in terms of how people, spaces and activities in museums can enable children to access and remember objects in museums more readily.

Museums can also exemplify and give caregivers indirect guidance on how to support and facilitate learning for their young children. By focusing on the family as learners and by promoting conversations and collaborations among adults and children, museums can be facilitators rather than obstacles to family exchange (Lifschitz-Grant 2018).

Experts and specialists can be highly effective facilitators for young children's learning. For example, Andre, Durksen and Volman (2017) report on how artists facilitated art exhibits by being on hand to talk with and accompany young visitors. Similarly, Dooley and Welch (2014) noted how artists (acting as on-gallery facilitators) pointed out technical features in art, directing children's attention by saying 'Look at this'. Lifschitz-Grant (2018) observes how facilitators can model how to prompt children's engagement by praising their own artistic interpretations, such as "Every tree looks so different. It looks like your tree is …"

It is important for museum staff to receive specialist training in 'under-fives friendly' approaches (Hackett, Procter, and Kummerfeld 2018). For example, prior training about young children's capabilities greatly benefited the success of the '*Hello, Pythagoras!*' (in an unnamed Children's Museum in Western Europe) exhibit that provided opportunities for toddlers to learn about maths and science (McInnes and Elpidoforou 2018). Here, museum staff facilitated children's engagement by encouraging them to look at themselves in the mirror (ego play), explore objects (exploratory play), walk around (active play), surprise one another (communication play), create buildings with construction materials (creative play) and play with puzzles (problem-solving play).

Children's learning can be facilitated by thoughtfully designed immersive museum spaces and activities as well as by people. For example, in the Chicago Children's Museum, USA, families with children aged 4 to 6 years received engineering instructions and experimented with a key engineering principle, bracing, prior to solving two engineering problems (Marcus, Haden and Uttal 2018). Some families then also received instruction on how to transfer that engineering knowledge across problems, whilst other families did not receive transfer instructions. Families were then taken to a permanent exhibit display and asked to fix a wobbly



bridge. The study found that the combination of engineering instructions with instructions about how to transfer knowledge led to a higher success rate in the practical task suggesting that engaging with a science concept in diverse ways, including object display, instruction and hands-on activity, is highly beneficial for learning.

3.7 DO CHILDREN'S OWN COLLECTIONS SUPPORT THEIR UNDERSTANDING OF MUSEUM OBJECTS?

None of the studies in this review focussed on children's own private and personal collections, so we have no research-informed evidence reporting on how individual children's own collections might influence their interest in and understanding of museum objects. This question therefore appears to highlight an under-researched phenomenon.

However, one study, illustrated below, may be relevant in this regard, as it reports on how 4-5-year-old children's curation of their own classroom museum enabled them to learn about museums by experiencing the curatorial process in an everyday context (Hope 2018).

EXAMPLE: A child-curated museum in a primary school classroom, Tower Hamlets, London, UK (Hope 2018)

In this study, 4- and 5-year-old pupils were told by their teacher that 'Alien Meanies' might visit the school and mindlessly ransack objects unless it was clear to the Meanies that the objects were important to the children. The teacher suggested that the children might curate their own small classroom museum, by collecting and curating classroom objects that the children wanted to keep safe from attack by the Meanies, and by displaying them in creative, multi-sensory ways so the meanies could understand what the objects were. The project encouraged children to explore and make new meaning about the objects through the curatorial process. The children were able to select and define the collection objects on their own terms, and these curatorial experiences increased their curiosity and knowledge about the objects. It also gave them greater understanding of museums and galleries, for example:

J: I put the worm there so the meanies can't touch it [on top of an overturned cot and covered in masking tape]
Interviewer: Do you think they should only be able to look at it?
J: Yes . . . it will get dusty and dirt . . . No, don't touch it! Look at it [directed to other children]
S: We need a box to put it in, so they don't touch it. It might get broken.
S: Look at my sign! I put it with the train.

4. REVIEW METHODOLOGY

We[5] conducted our search for peer-reviewed academic publications in July 2019, following a six-step procedure, outlined in Table 1. Our final review was based on 43 sources (see Appendix 2), including: 39 journal articles; 3 reviews of research (Andre, Durksen and Volman 2017; Griffin 2004; Munley 2012), and one doctoral dissertation (Kim 2009). These papers report on studies conducted in science museums, science centres, natural history museums, art galleries/museums, and children's and national museums that house STEM-related collections and exhibits (see Table 2).

STEP	DESCRIPTION	NUMBER OF PAPERS
1	Searched electronic databases with combinations of key words (e.g. learning, museum, young children, object)	3557
2	Excluded duplicate articles	2936
3	Excluded all papers where it was clear from the abstract that exclusion criteria applied, and located full texts for all remaining papers	346
4	Screened full texts against exclusion criteria	47
5	Screened articles for quality	43
6	Applied detailed codes to full papers	43

Table 1: Article selection process

MUSEUM TYPE	NUMBER OF PAPERS
Science museum/centres	3
Children's museums (inc. some STEM-related)	10
National/regional/social history museums (inc. some STEM-related)	6
Across multiple museum sites (inc. some STEM-related)	10
Art gallery/museums	5
Natural history museums	6
Classroom museums (in pre-school/school)	2
Virtual museum	1
Total	**43**

Table 2: Review database according to museum type

[5] The REA team comprised: Rosie Flewitt (REA Project Lead); Yana Manyukhina (Research Assistant); Mukdarut Bangpan (expert advisor on EPPI software tool and REA methodology); Dominic Wyse (Project Lead for HHCP; quality assurance).

4.1 SEARCH STRATEGY

We searched six databases using free-text terms, including two key concepts (museum and children) and relevant terms (see Appendix 4). One reviewer piloted the search on one database, inspected the studies identified from the search, then revised and finalised the search strategy. This process was iterative and involved discussion between review team members. We checked the reference lists of key literature and included any studies of potential relevance. See Appendix 4 for further details of searches. Throughout the review process, we used an online systematic review software system EPPI-Reviewer (Thomas et al., 2010) to facilitate the screening, data extraction, and analysis processes, and we were supported by an academic expert in the use of this software tool (Bangpan). See Appendix 3 for detailed exclusion criteria.

Table 3: Initial Eligibility Criteria

ASPECTS REPORTED	ELIGIBILITY CRITERIA
Focus population	Broad age range 3-17 years (or older), excluding all papers that did not include children age 0-8 years
Topic focus	Studies related to children's learning in museums, and how children interact and objects in museums (see *Glossary*)
Setting	Studies that focussed on museums or galleries or centres that display artefacts, including art, natural history, or STEM
Types of evidence	All types of research designs but excluded papers that were not supported by research evidence. In some cases, the supporting research evidence was referred to as published in related papers arising from the same research project. We excluded books, Masters theses, conference proceedings.
Publication date	All studies published during and after 2000

4.2 SCREENING PROCESS AND DECIDING ON THE RELEVANCE OF STUDIES

Two team members independently piloted the eligibility criteria on a sample of 10 studies and we resolved any discrepancies as a team. We then conducted a two-stage screening process to the entire data set, applying the exclusion criteria initially to the titles and abstracts of all studies identified through the database searches. We subsequently retrieved the full texts of the remaining 346 papers, including all studies that had insufficient information to make decisions based on the title or abstract. Using the eligibility criteria listed above, we examined all full-text 346 papers all studies in-depth. This process reduced the sample to 47 studies.

4.3 APPRAISING THE QUALITY OF STUDIES

We classified each of the 47 papers as reporting on study designs that were quantitative, qualitative or mixed-methods. We then assessed the quality of all qualitative studies using CASP (Critical Appraisal Skills Programme 2018) quality assessment frameworks. The quality

assessment framework for quantitative studies was informed by the Mixed Methods Appraisal Tool (MMAT) (Pluet et al. 2011). A sample of 14% of studies was independently assessed for quality by a fourth team member (Wyse). This process established the final data set of 43 studies.

4.4 CODING PROCESS

Two reviewers developed, piloted and agreed a coding framework to address the research question (see Coding Framework in Appendix 5) to extract relevant data from all studies judged to be high and medium quality. The coding tool contains questions about key characteristics of research evidence including population, focus of the study, types of learning, objects, and interactions and study methods.

4.5 SYNTHESIS

Three reviewers performed line-by-line coding of all studies in the dataset, using the *EPPI-Reviewer* systematic review software. The project lead subsequently conducted a narrative synthesis based on the coded data extracts.

4.6 RESULTS

The searches from the bibliographical databases identified 3557 citations. We excluded all duplicates from the review, resulting in 2936 citations included for titles and abstract screening. Of 2936, 2590 were excluded when the eligibility criteria were applied against titles and abstracts, leaving a total of 346 reports included for full text screening. Of these, 336 full text papers were successfully retrieved and subsequently screened using the same eligibility criteria. Four studies were excluded based on quality. A total of 43 studies were ultimately included in the review. Figure 2 presents a flow of the selection process of the studies in this review.

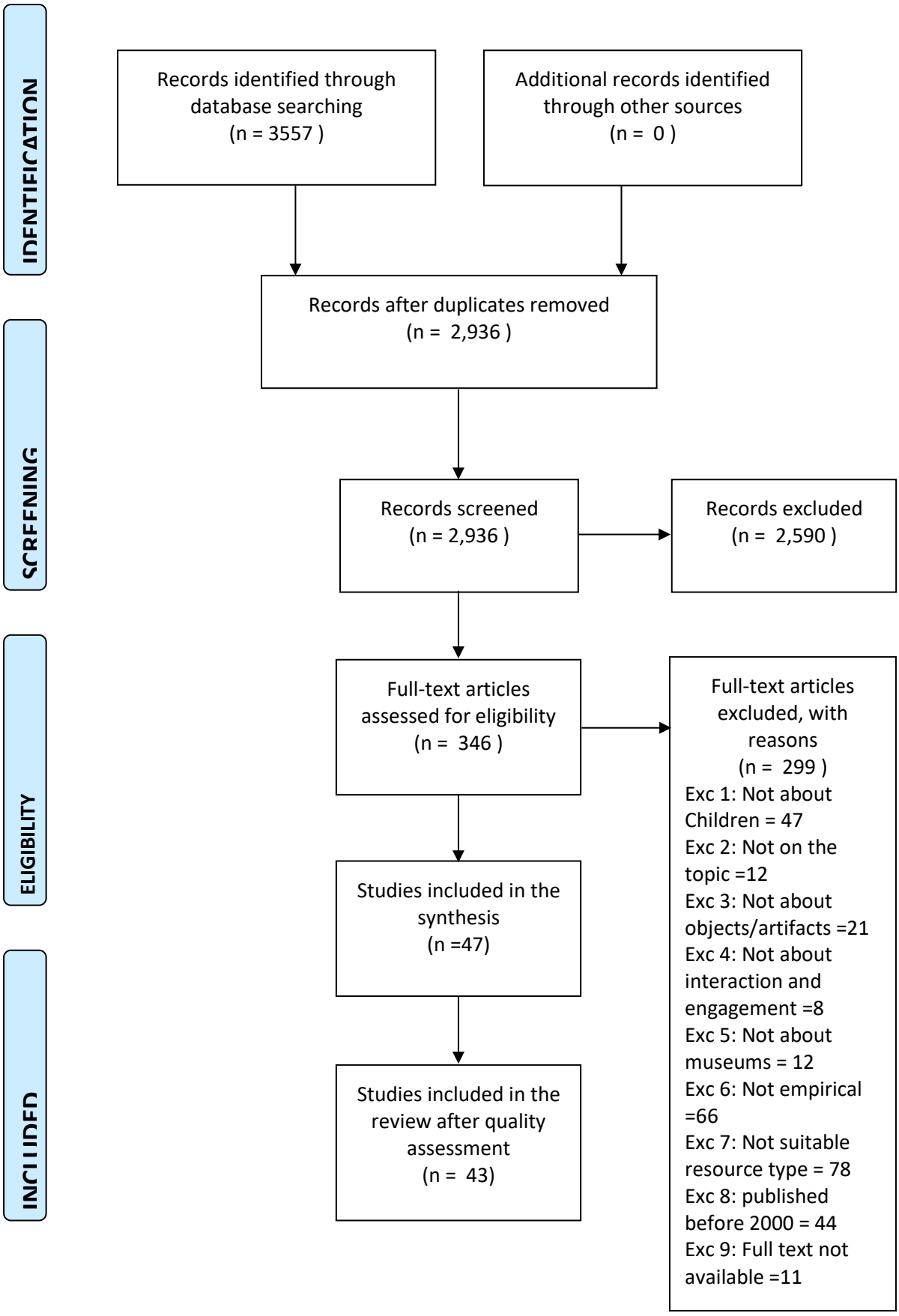


Figure 2 Selection of studies in the review

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APPENDIX 2: OBJECTS IN THE SCIENCE MUSEUM COLLECTION

In total, the Science Museum Group Collection contains 7.3 million items (including photographs and archival material), of which approximately 425,000 are objects. These objects have unique and compelling stories and form the basis of the Group's activities, from curating public exhibitions to the museum's educational work. Standout objects in the Science Museum Group Collection include:

Alan Turing's Pilot ACE computer;

One of the first models used to represent atoms;

Charles Babbage's drawings and models;

Dorothy Hodgkin's model of penicillin;

Helen Sharman's spacesuit and Tim Peake's spacecraft;

Amy Johnson's Gipsy Moth aircraft;

Famous locomotives from Stephenson's Rocket and Sans Pareil to Mallard and Flying Scotsman;

The world's earliest surviving photographic negative.

The Science Museum collection traces its origin back to the 1851 Great Exhibition. Among the items cared for by the Science Museum are:

- 140,000 medical objects, including many on long-term loan from the Wellcome Trust
- 38,000 objects relating to railway locomotives, technology and railway life
- 26,000 scientific instruments
- 17,000 objects of photographic, cinematographic and televisual technology
- 7,000 artworks

Further information about the Science Museum collection is available here.

APPENDIX 3: INCLUSION AND EXCLUSION CRITERIA

Inclusion	Exclusion criteria
Population	Exc 1: Not about Children aged 0-8 years
Topic focus	Exc 2: Not on topic Exc 3: Not about objects/artefacts Exc 4: Not about interaction and engagement
Setting	Exc 5: Not about museum
Type of evidence	Exc 6: Not empirical Exc 7: No suitable resource type: Books, MA theses, conferences proceedings
Date	Exc 8: Published before 2000
Include for full text	
Include in the review	

APPENDIX 4: SEARCHING (JULY, 2019)

British Education Index

Search terms: museum AND objects OR collections AND children OR young visitors OR young people OR students OR early childhood education OR nursery OR kindergarten (ALL TEXT)

limit by: English

ERIC (EBSCO)

Search terms: museum AND objects OR collections OR artifacts OR artefacts AND children OR young visitors OR young people OR students OR early childhood education OR nursery OR kindergarten (ALL TEXT)

limit by: English

ERIC (ProQuest)

Search terms: museum AND objects OR collections OR artifacts OR artefacts AND children OR young visitors OR young people OR students OR early childhood education OR nursery OR kindergarten (ANYWHERE)

limit by: English, peer-reviewed

AUSTRALIAN EDUCATION INDEX

Search terms: museum AND objects OR collections OR artifacts OR artefacts AND children OR young visitors OR young people OR students OR early childhood education OR nursery OR kindergarten (ANYWHERE)

SCOPUS

Search terms: museum AND objects OR collections OR artifacts OR artefacts AND children OR young visitors OR young people OR students OR early childhood education OR nursery OR kindergarten (ALL FIELDS)

Limit to: English

1550 RESULTS

Social Sciences Citation Index = Web of Science

Search terms: museum AND objects OR collections OR artifacts OR artefacts AND children OR young visitors OR young people OR students OR early childhood education OR nursery OR kindergarten (ALL FIELDS)

Limit to: English

APPENDIX 5: CODING FRAMEWORK: CHARACTERISTICS & CONTEXTS OF STUDIES

Domains	Coding details
1) Research methods	• Quantitative • Qualitative • Mixed • Review • Not applicable
2) Child age	• 0-8 years
3) Phase of education	• Early years education/early learning/preschool/EYFS • Primary/key stage 1 • Not specified
4) Type of museum	• Science museum/science learning centre • Art gallery/art museum • Natural history museum • Children's museum • Social history/national/regional museum • Classroom museum (pre-school/school setting) • Virtual • Multiple • Various/doesn't specify
5) Type of objects/artefacts	• Large • Familiar to children • Moving • Authentic • New/unfamiliar • Computer/technology
6) Learning area	• STEM/understanding the world • Arts • Humanities
7) Ways of displaying	• Part of a collection • Stand-alone (not part of a collection) • Contextualised • Decontextualised • Interactive/hands-on/immersive • Fixed • Open • Closed

8) Nature of interaction	• Solitary (child-environment)
	• Child-technology
	  ○ Mobile phones/guides
	  ○ Ipads

Domains	Coding details
	○ Computer / computer simulations / 3D& VR ○ Video ○ Other • Child-people ○ Guided/explanatory ○ Scaffolded ○ Facilitated ○ Collaboration (pair/group) ○ Dialogic/questioning/enquiry ○ Child-led
9) People child interacting with	• Peers ○ Siblings ○ Classmates • Adults ○ Museum staff ○ Parents/carers ○ Teachers
10) Child response	• Attraction/attention • Interest • Deep engagement • Displaying agency/taking ownership • Building on existing knowledge/interests • Imitation
11) Degree of choice	• Free choice • Limited choice • No choice
12) Type/nature of experiences	• Familiar • Contextualised • Live/performance-based • Facilitated • Kinaesthetic/tactile • Storified • Linked to prior experiences (classroom/kindergarten/home etc) • Repeated • Child-led • Tailored (age, interests, knowledge, needs) • Multisensory • Fun/enjoyment • Play-based • Unusual/unfamiliar
13) Theoretical approach/framing	• Sociocultural theory • Multiple intelligences

Domains	Coding details
	• Social cognitive • Social practices • Piaget's theory • Developmental theory • Naive theories • Not stated
14) Non-physical aspects of museums	• Museum websites • Virtual collections • Museums on social media • Learning resources/activities • Not stated
15) Generally noteworthy	• Please specify